Comprehensive Environmental Assessment of Engineered Aluminum Nanoparticles in DoD Materiel: Evaluation before Acquisition

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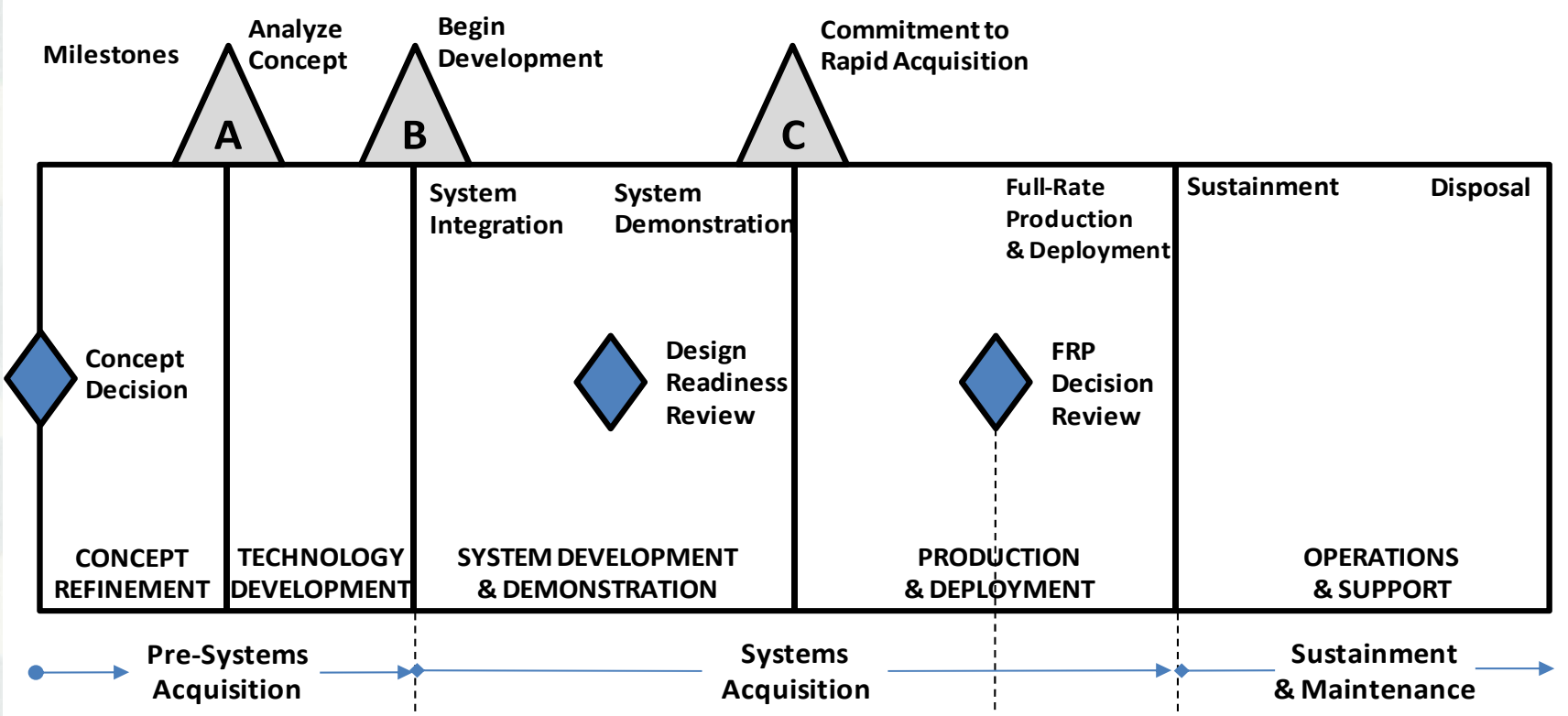
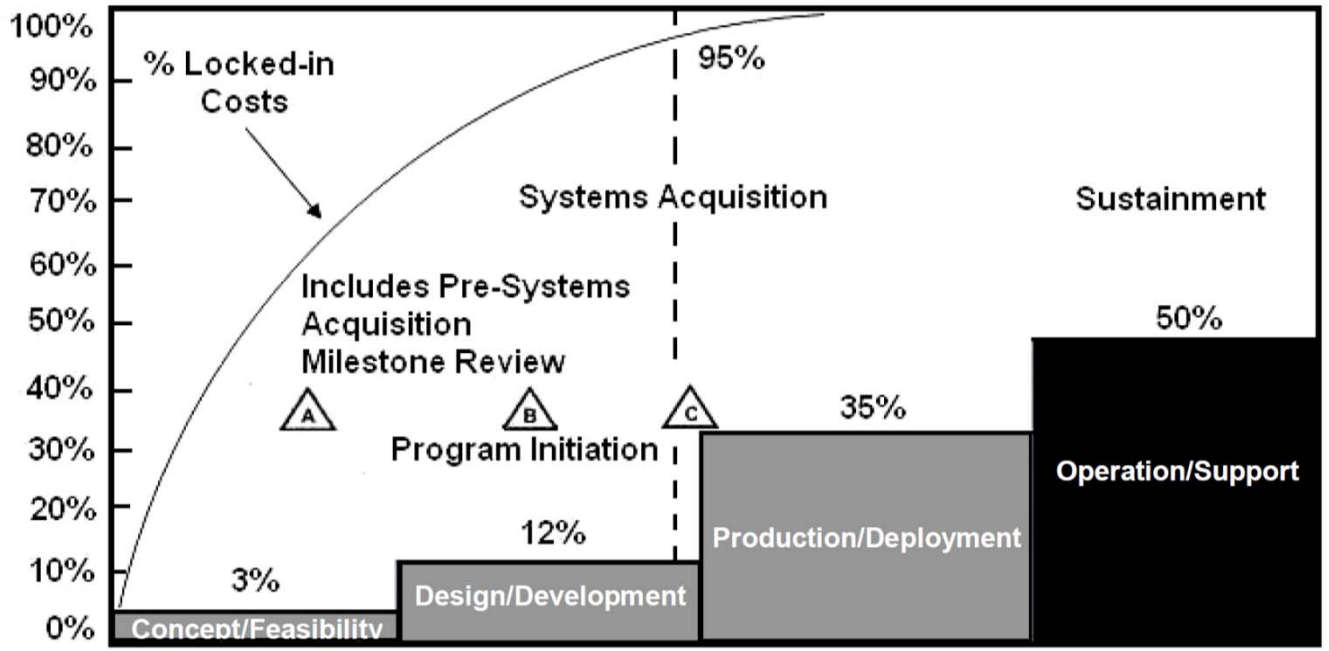
Stages of Acquisition Process Benefiting from Environmental Hazard Assessment



Technology development and acquisitions process. Adapted from Mike McDevitt, Installations Management Command

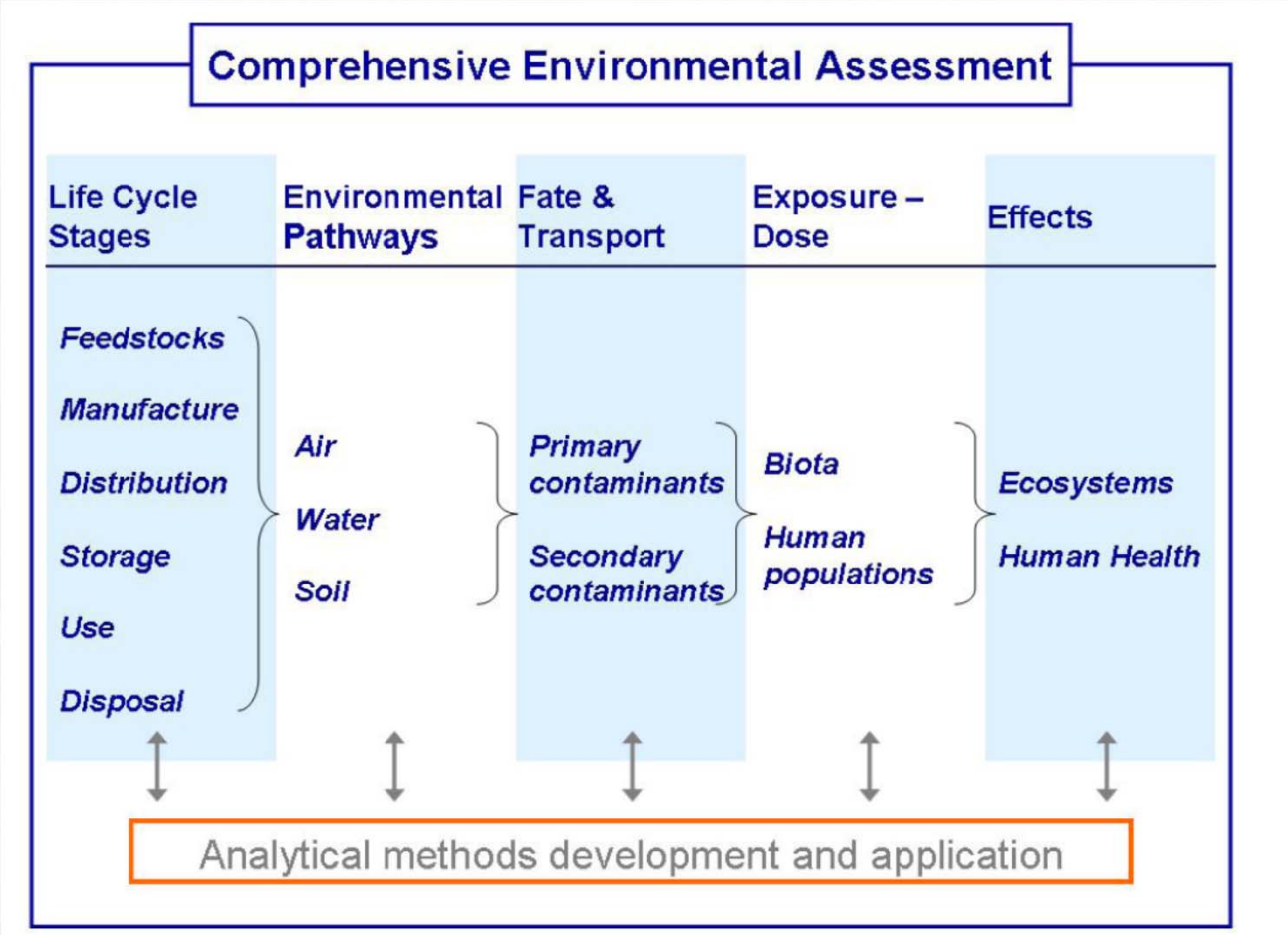
DoD Materiel Development and Costs



Phase graphics: Robert Cramwell, Sandia National Laboratories, *Ground Vehicle Reliability*, DoD Maintenance Symposium, November 13-16, 2007.

- It is estimated that over 85% of the costs of technology occur after systems acquisition

Comprehensive Environmental Assessment (CEA)



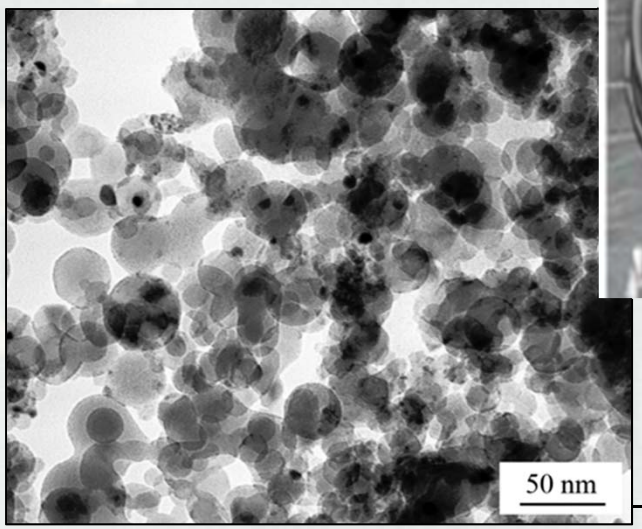
Adapted from Davis, 2007

CEA Process

- **Identify the question(s)**
  - Sources
  - Life cycle stages, fate & transport, matrices, exposure, effects
  - Developed methods and standardized protocols
- **Obtain diverse perspectives**
  - **ODUSD** Chemical & Material Risk Management
  - **NNCO** National Nanotechnology Coordination Office
  - **ARMY -** ARDEC , Army Institute of Public Health, ERDC
  - **Navy -** NSWC-IHD
  - **Air Force -** Air Force Laboratory Human Effectiveness Directorate
- **Use collective judgment method**

Adapted from Davis, 2007

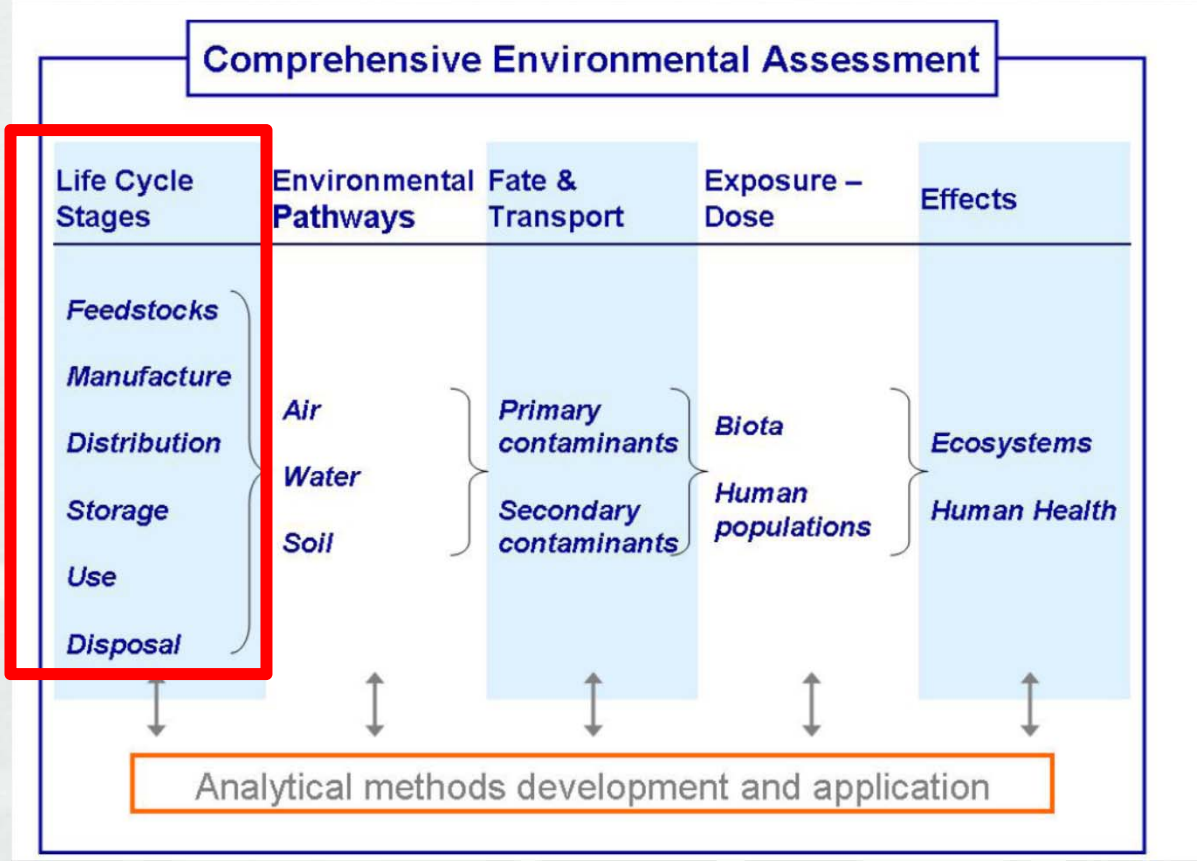
ERDC CEA Case Study: Engineered Aluminum Nanoparticles



Applying CEA approach to nanotechnology in the R&D Phase

- **Lack of mature industries**
- **Data lacking or evolving**
- **Characterization of materials**
- **Uncertainty is high**
- **Identify and prioritize knowledge gaps**

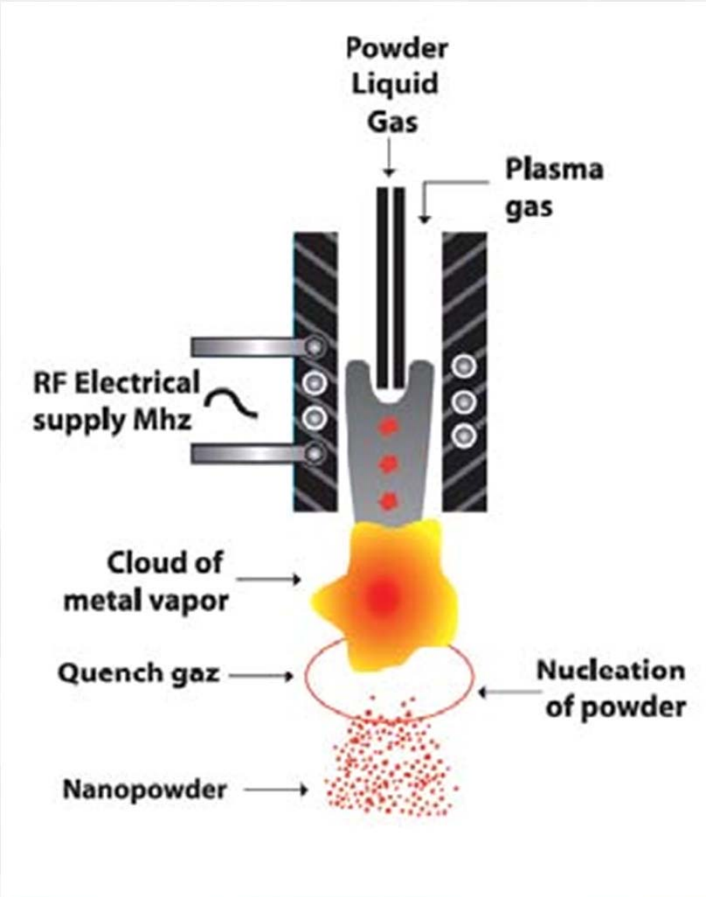
CEA: Life Cycle Stages of nano-Al



Site Visit: ARDEC Picatinny Arsenal Nanotechnology Research Center

- Operates North America's largest Radiofrequency (RF) Induction Plasma reactor (Tekna Plasma Systems) pilot plant for nano-Al and high performance nonmaterial:
  - ► Plasma Synthesis
  - ► 10 micron aluminum powder feedstock
  - ► Use of nano-aluminum still in the R&D phase
  - ► Characterization FE-SEM ,XRD, XRF, XRD, BET, Thermal analysis

CEA: Life Cycle Stages – Feedstocks



- Powder feeder system introduces10 micron aluminum powder
- Plasma system combines “top down” and “bottom up” process, solid precursor vaporized and quenched enabling synthesis of nano-Al
- Feedstock is aluminum oxide passivated in situ with an approximately 5 nm oxide coating
- Nano-scale powder collected in stainless steel canister inside glove box

CEA: Life Cycle Stages – manufacture

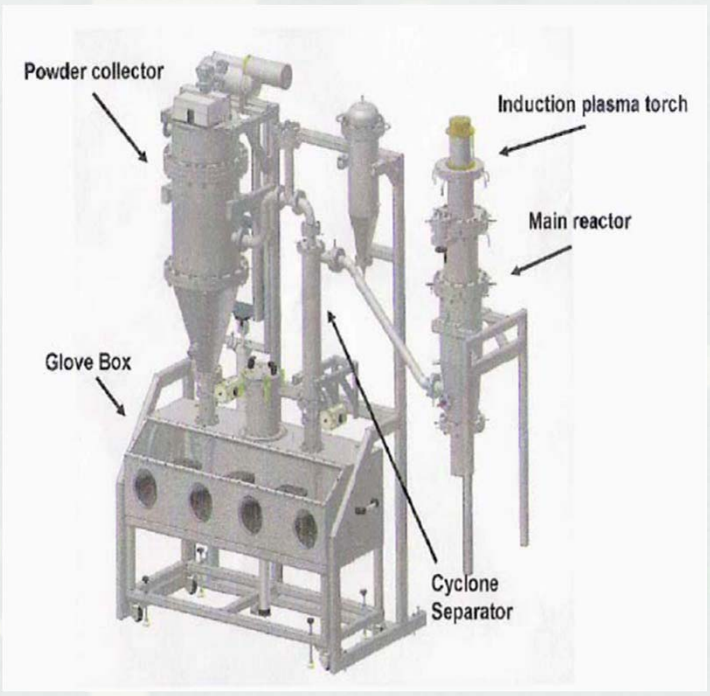
Picatinny Arsenal Nanotechnology Research Center maintains two 300kiloWatt RF Tekna Plasma Systems:

•Metals and metal oxides

•Ceramics

- Cyclone classifier separates product by size, nano-scale powder is collected in a collection chamber under argon
- Synthesis efficiency is 10:1 nanopowder to aggregates, aggregates are stored for research purposes

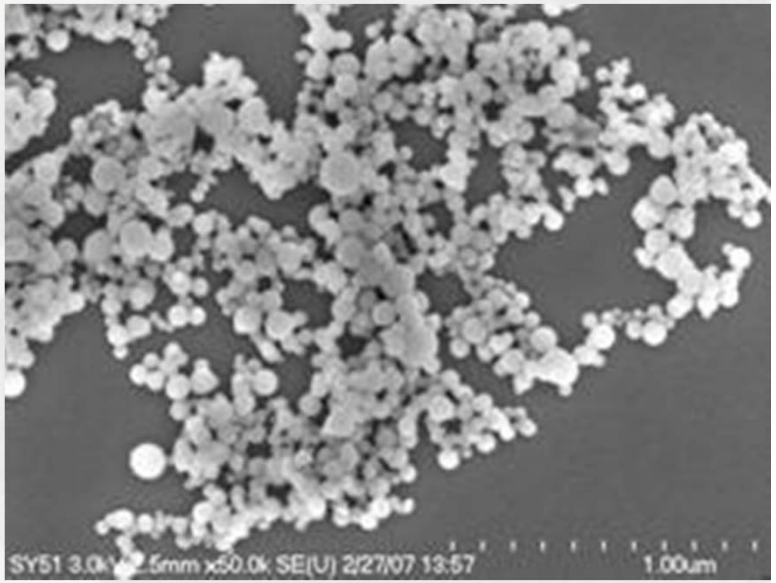
CEA: Life Cycle Stages – manufacture



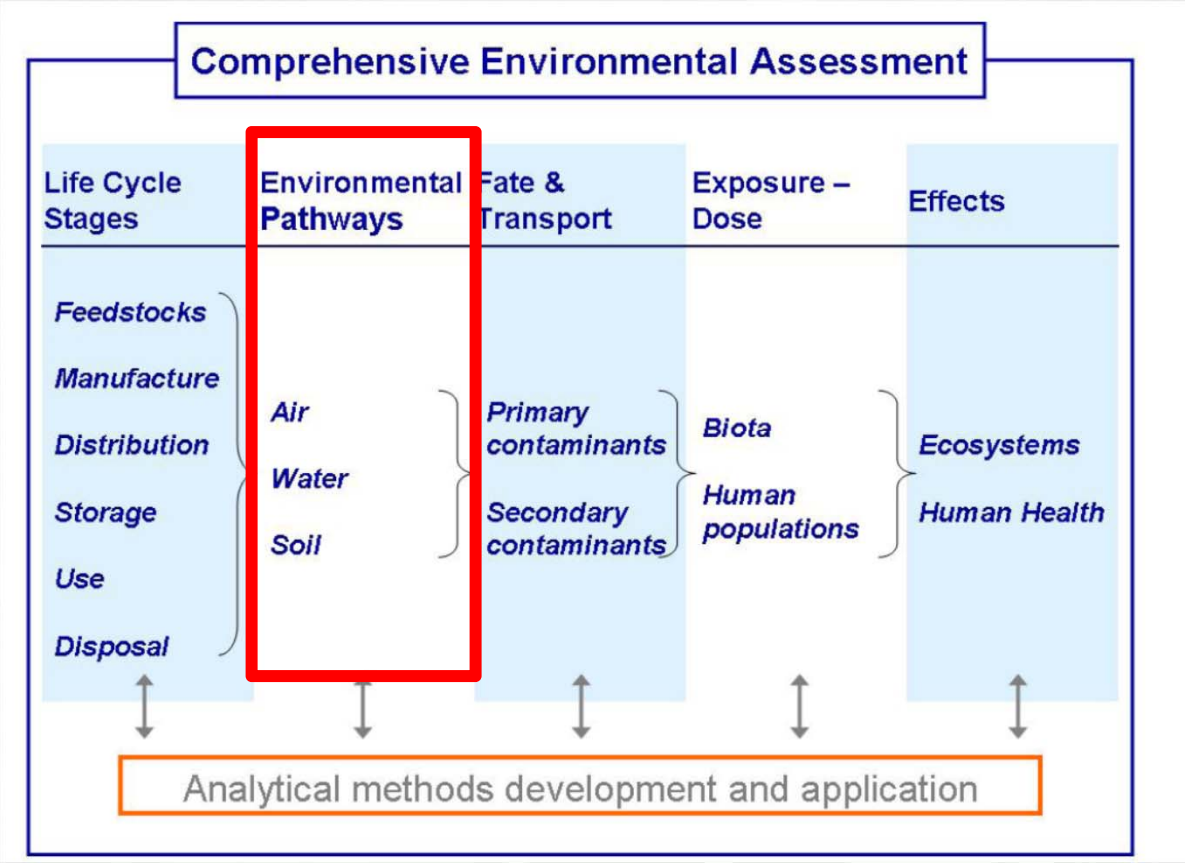
- HEPA filtered fan with 100 cfm exhaust hood, hydrogen sensors in enclosure to detect leaks
- Reactor process capacity of 4hrs per day with 4 hours remaining to rapidly characterize product FE-SEM ,XRD, XRF, XRD, BET, Thermal Analysis, etc.

CEA: Life Cycle Stages – distribution and storage

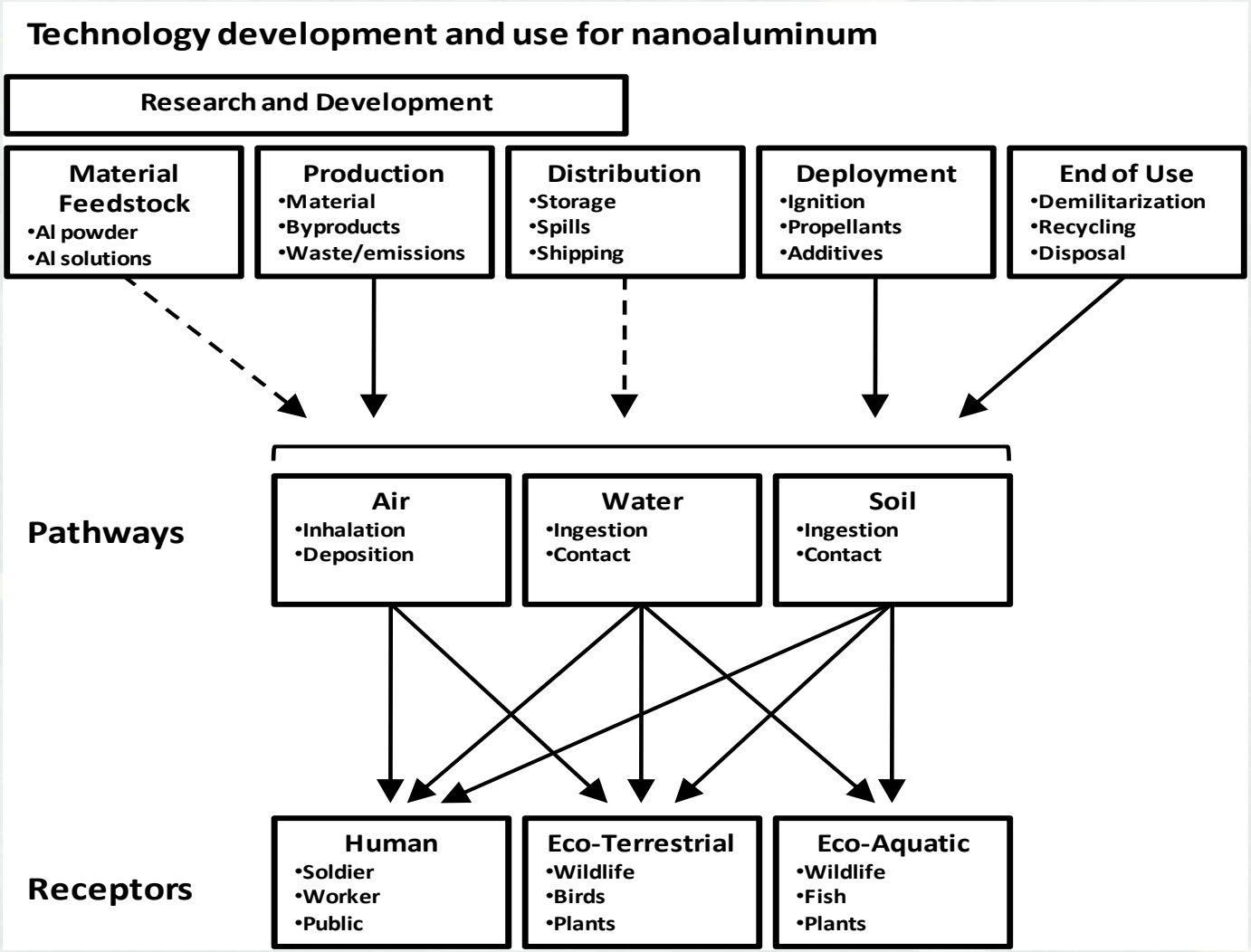
- Use of nano-aluminum still in the R&D phase
- Stored under inert atmosphere
- Aggregates are stored at the facility (still have research value),
- Current synthesis of 200g batches for rapid characterization
- Stability studies indicate no loss in surface area, however a 20% loss in reactivity due to oxygen diffusion



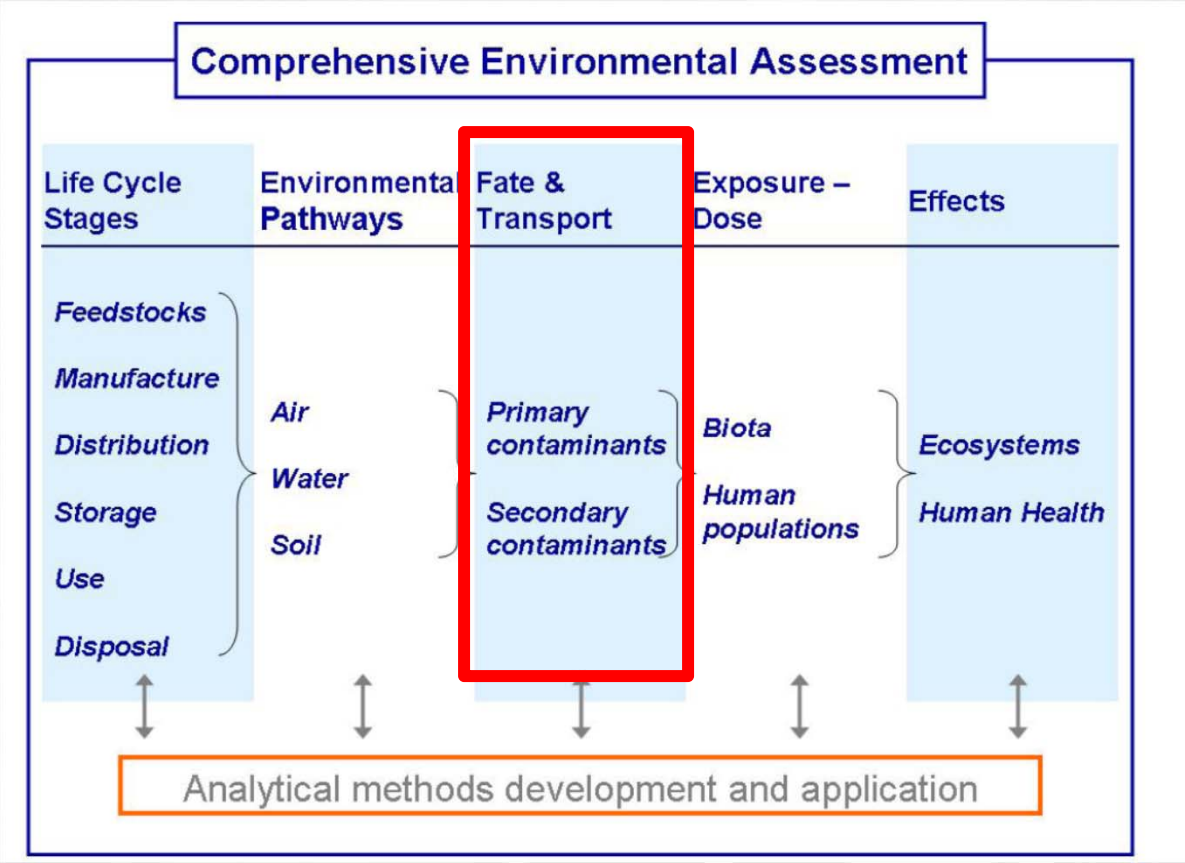
CEA: Environmental Pathways of nano-Al



CEA: Environmental Pathways of nano-Al



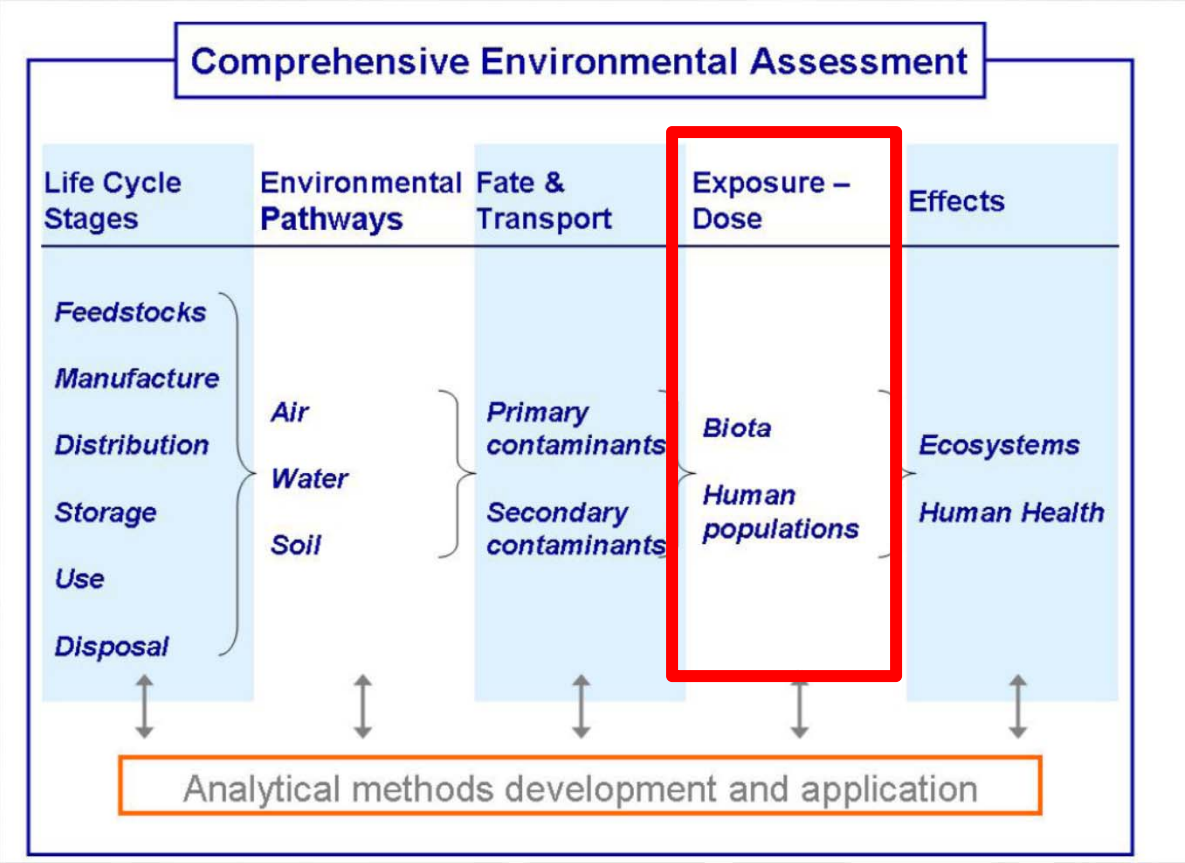
CEA: Fate and Transport of nano-Al



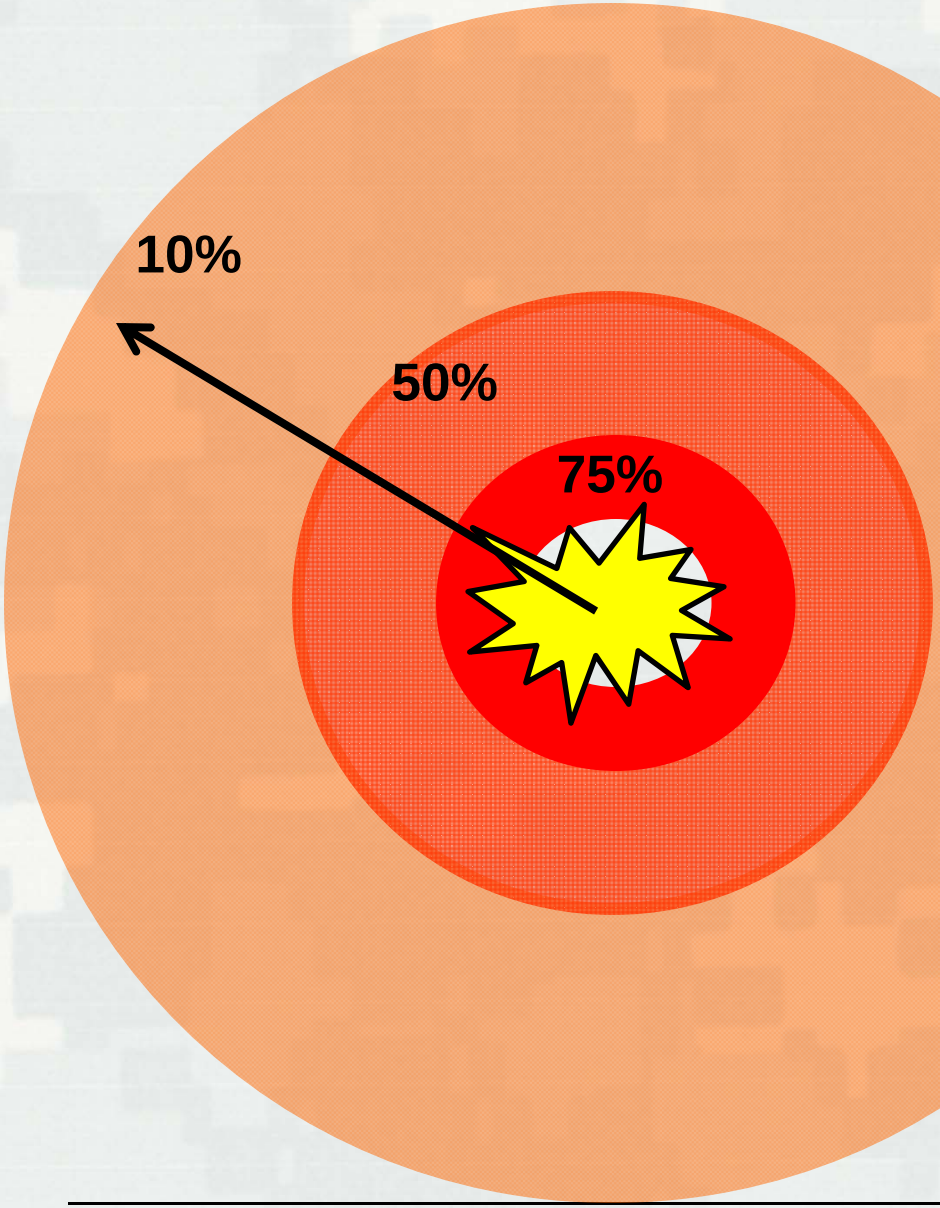
CEA: Fate and Transport of nano-Al

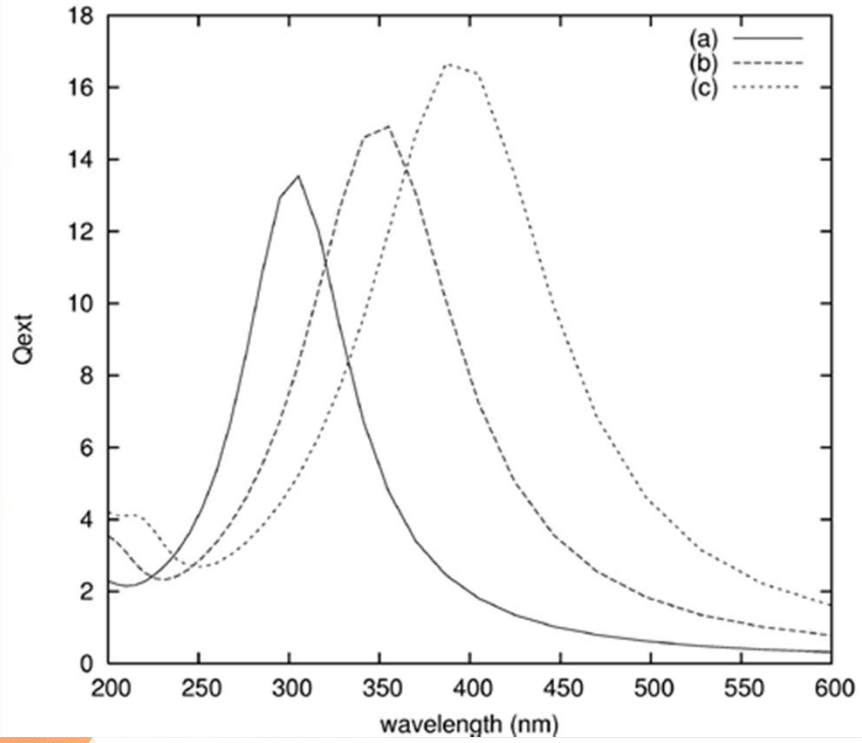
- **Particle size dictates oxidation potential**
- **Nano-Al/ Al_2O_3 interacts with soil, water, and strongly with humic acids**
- **Highly agglomerates → affects mobility in soil**
- **Surface charge changes with leachate → alters mobility**
- **Micron-sized Al_2O_3 has greater sorption than nano-Al_2O_3**

CEA: Exposure-Dose of nano-Al



CEA: Exposure-Dose
% content of nano-Al





Plot of extinction values for Al triangular prisms (Faber et al. 2008)

CEA: Exposure-Dose of nano-Al

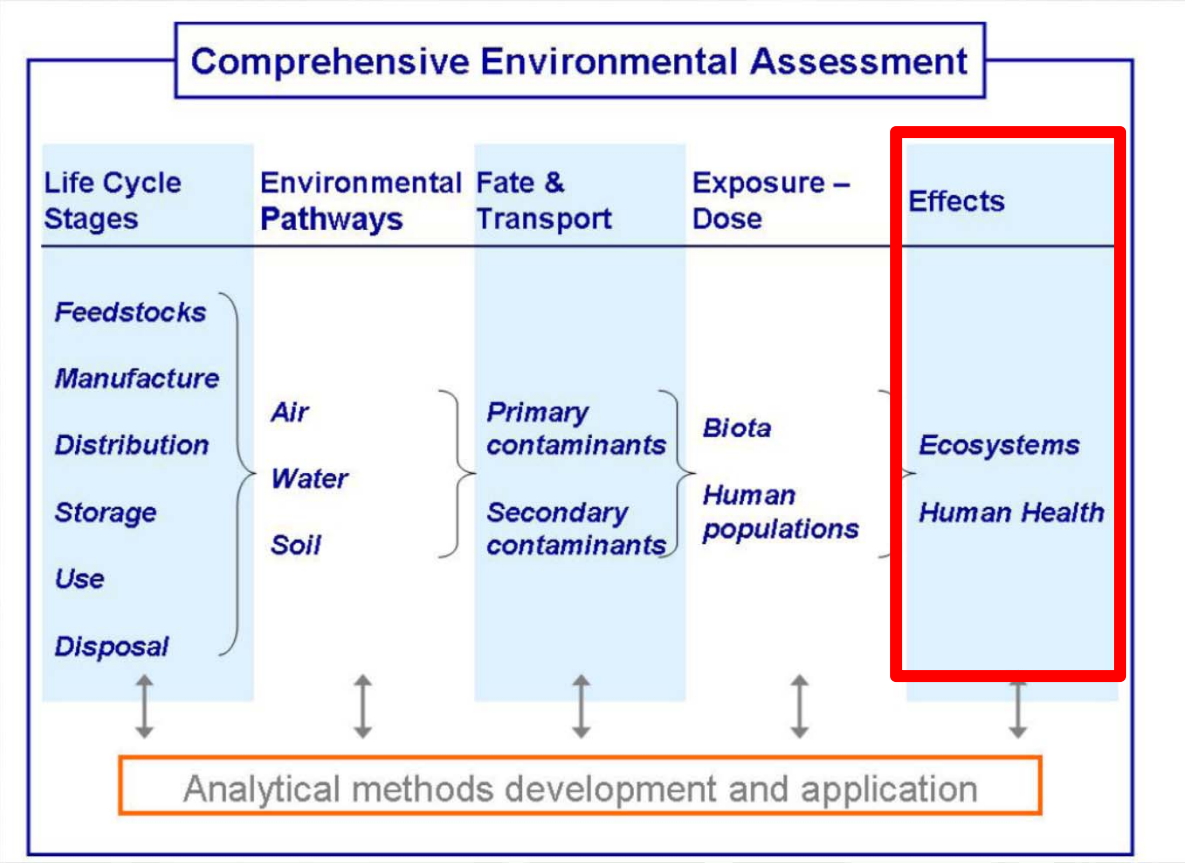
Most likely routes of nano-Al/Al_2O_3 exposure: Inhalation > Dermal > Internal (oral, ip, iv)

- **ARDEC-NIOSH collaborative framework** *"Nano-powder Synthesis & Associated Safety Precautions at ARDEC"*

TWA and other occupational exposure values?

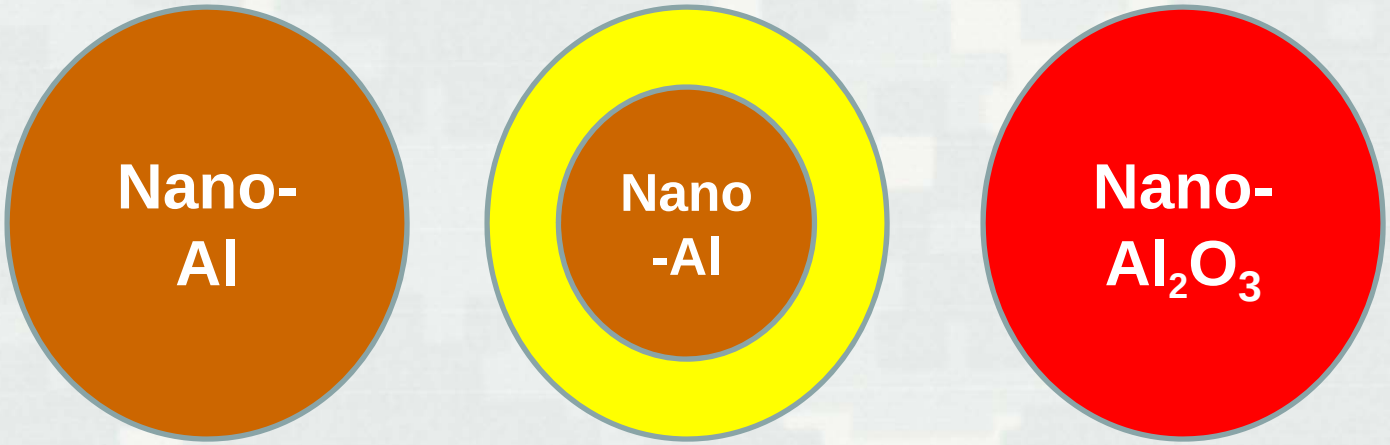
R&D laboratory evaluations of occupational exposures?

CEA: Effects of nano-Al



CEA: Problems with Effects of nano-Al

- **Nano-Al/Al_2O_3 is highly agglomerated**
- **Is aged nano-Al the same as nano-Al_2O_3?**



CEA: Effects of nano-Al

Ecosystems:

- Less toxic to daphnids and algae than other NPs
- More toxic to juvenile zebrafish than adults
- Causes atherothrombotic events in zebrafish
- Produces differential effects on benthic organisms
- Mildly toxic to bacteria
- Mildly phytotoxic (root growth inhibition) due to ROS
- Soil nematodes and earthworm reproduction negatively affected

CEA: Effects of nano-Al

Human Health:

1. Inhalation –
Negatively affects alveolar macrophages function

2. Dermal –
Dermal contact may increase proinflammation, dermatitis

3. Internal –
Neurotoxicity (blood brain barrier disruption) and

Increased genotoxicity

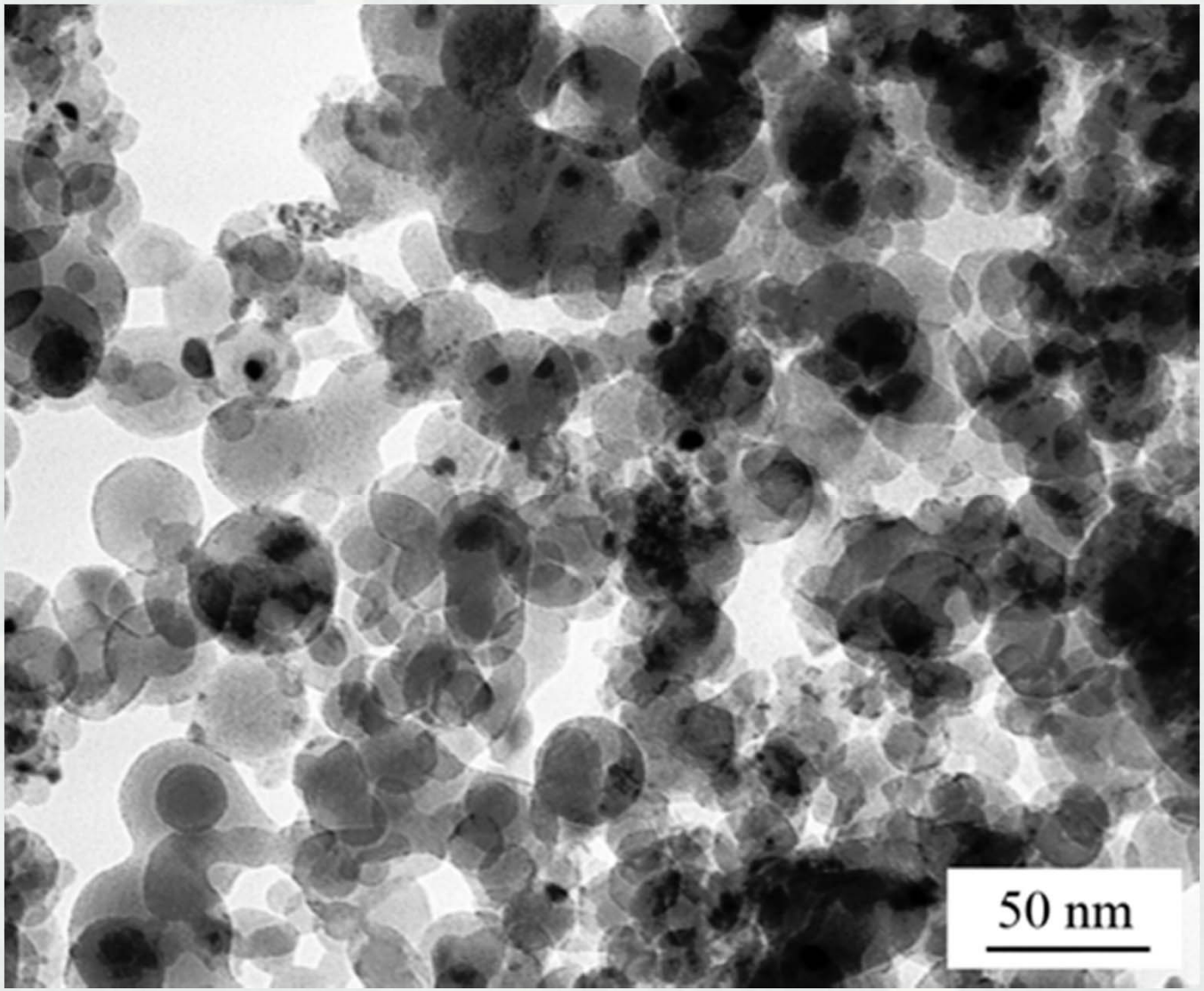
Preliminary Conclusions

- Potential sources and releases of nano-Al to the environment that will likely occur through air, water, or soil exposures through the production, use, and disposal of nano-Al propellants, igniters, and additives.
- However, these preliminary findings are the result of an assessment from the R&D community.
- Data collection is still required to gain a better understanding of the future deployment and handling of nano-Al as a military technology.

Data Gaps / Moving Forward

- **Life Cycle:** Further collaboration required within the R&D community such ARDEC, NSWC-IHD, and AFRL to discuss life cycle phases.
- **Environmental Pathways:** This is a potential laboratory and field research project (modeling and hyperspectral imaging analysis for nano-Al/energetic combustion analyses)
- **Exposure:** Exposure to biota and humans is perhaps the biggest area of uncertainty in this entire nano-Al CEA.
- **Environmental Fate:** Once nano-Al has moved beyond the R&D phase, field testing will be imperative to study nano-Al/Al2O3 propellants and energetics in the field.
- **Effects:** Data needs to reflect of actual particle sizes, i.e,. nanoparticle agglomerates vs. monodispersed nanoparticles.

Questions?



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